Influence of laser scanning speed on the rotary wear behaviour of deposited Ti6Al4V alloy and Cu

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Abstract

Laser metal deposition (LMD) is an additive manufacturing technology that involves the combination of metallic powder and laser beam for its consolidation. The process parameters involved in LMD need to be well understood and implemented correctly before the optimal process can be achieved. This paper reports the effect of scanning speed on the wear behaviour of laser deposited samples. The rotary wear method was adopted in order to understand the relationship in the radii of the wear track. The scanning speeds were varied from 0.0083 m/sec to 0.0333 m/sec while the laser power of 1.0 kW, the powder flow rate of 1 rpm and the gas flow rate of 2 l/min were kept constant. Some lateral cracks were observed in the microstructure which was due to the effect of the thermal stress that was induced during cooling. The laser deposited samples are suitable for repair in marine industry as the manufacturing process will provide a great control to the desired material properties with superior performance.

Keywords: Cu, laser metal deposition; wear measurement; SEM; Ti6Al4V alloy

1.0 Introduction

Titanium alloy (Ti6Al4V) is the most applicable alloy in the aerospace, marine, biomedical, chemical industries, energy, automotive industrial services and many more since it unveils a combination of mechanical, physical and corrosion- resistance properties [1, 2]. The improvement in the mechanical properties of the alloy has generally been realized through the blending of other alloying compounds [3, 4]. The α-stabilizers such as Aluminium, impart solid solution strengthening and the β-stabilizers such as Copper (Cu), introduced the β-phase in the α-phase microstructure in order to form the α/β phase with better ductility and fatigue strength [5]. Copper is a high thermal conductive element with good corrosion resistance and showed passivating adherent protective oxide films that relatively resist corrosion at room temperature [6]. The study on the surface modification of titanium grade 2 using nano-thin films of Cu for biofouling control has been investigated. The adhesion of bacteria cells on the material was treated for biofouling. In the sea water, the Cu based titanium alloy sample showed good improvement due to its resistance to biofouling and as a result of its toxicity to micro-organism. Within 15 days in sea water, epifluorescence was formed on the surface of titanium. It was concluded that the antimicrobial activity of the surface coated with Cu showed a decrease in the bacterial density [7]. Different alloying samples - Hastelloy G-30, Cu-Ni 70-30, stainless steel 304 and titanium were uncovered for a half year in continuous fresh seawater of the Gulf in Kuwait. Titanium sample was detected with no effect of the marine fouling on its potential stability while the potential for the three other alloys was shifted up to the more positive domain. The phenomenon was concluded to be attributed to the slow rate of bio-film formation during winter season on the surface of the tested alloys [8]. However, this paper presents the effect of scanning speed on the rotary wear behaviour of laser deposited Ti6Al4V alloy and Cu. Here, 50 weight percent (wt.%) of Ti6Al4V alloy and 50 weight percent (wt.%) of Cu were deposited onto Ti6Al4V alloy substrate. The microstructural effect and the rotary wear analysis were investigated on each sample.

2.0 Experimental procedure

The two powders used for the deposition are Ti6Al4V alloy and Cu in equal proportion (1:1). The powders were fed from two different hoppers attached onto a powder feeder. A rectangular plate of Ti6Al4V alloy with dimension of 102 X 102 X 7.45 mm^3 was used for the substrate and sand-blasted before use in order to sanitize the surface. Beam diameter of 4 mm and standoff distance of 12 mm were used for the deposition. The experimental matrix used in this study is shown in the Table 1.

Table 1: Experimental matrix

Sample Name	Z1	Z2	Z3	Z4
Scanning speed (m/sec)	0.0083	0.0167	0.025	0.0333

The laser power of 1.0 kW, gas flow rate of 2 l/min and powder flow rate of 1 rpm for each powder are kept constant. Following the guidelines in the Struers application note for preparation titanium, all the mounted samples were ground, polished and etched [9]. The Kroll's reagent (etchant) was prepared with 100ml of water (H_2O) + 5ml of Nitric acid (HNO_3) + 3 ml of Hydrofluoric acid (HF). Thus each sample was slightly deep into the etchant for 15 seconds prior to microstructural observation on the scanning electron microscope (SEM). Similarly, rotary wear test was conducted on the surface of the multiple track samples using a pin-on-disc arrangement on the UMT-2 CERT Tribo tester. Each sample was manually fixed in place on the sample holder and the tungsten carbide test ball (10 mm diameter) rotates on it for 1000 seconds using an applied load of 25 N and angular speed of 60 rpm ($\approx 2\pi$ rad/s).

3.0 Results and discussion

Figures 1 (a) to (d) display the macrographs and microstructures of sample Z1 deposited at a laser power of 1.0 kW and scanning speed of 0.0083 m/sec and sample Z3 deposited at a laser power of 1.0 kW and scanning speed of 0.025 m/sec observed under the SEM.

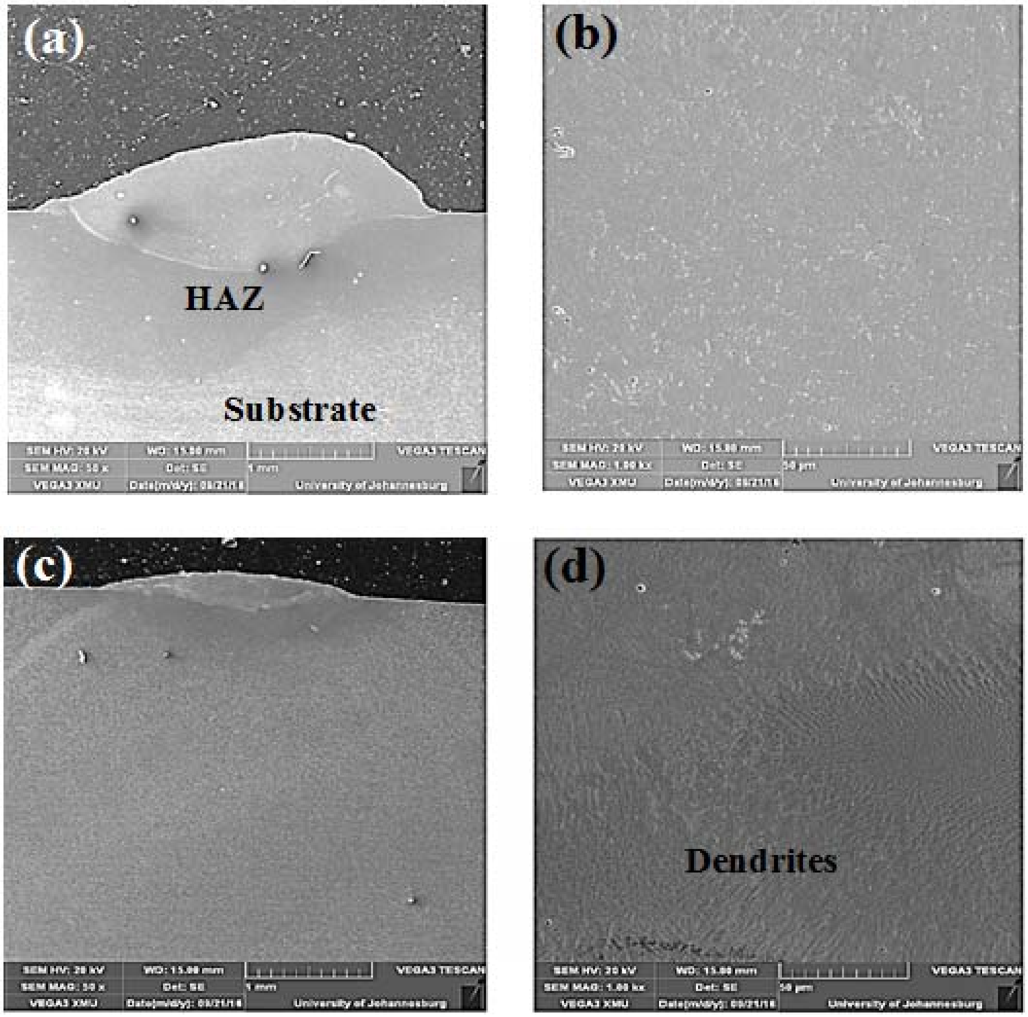

Figure 1: SEM of laser deposited sample, (a and b) Macrograph and microstructure of sample Z1 deposited with a scanning speed of 0.0083 m/sec; (c and d) Macrograph and microstructure of sample Z3 deposited with a scanning speed of 0.025 m/sec

The dendrites in sample Z1 are more formed in the deposit and elongated towards the fusion zone than the other deposited samples. There is evidence of lateral crack propagations in the deposited layer. The outsized variation in the thermal conductivities and the specific heat capacities of the deposited samples has contributed to the behaviour of crack initiation. Since the coefficient of thermal expansion of Cu is approximately twice that of Ti6Al4V alloy, the rate of cooling is slow with the greater amount of heat input. The slow scanning speed of 0.0083 m/sec has enhanced the robustness of the dendrites and α-Ti lamella as well as the migration of the β-phase as compare with other samples at high scanning speed. Cracks were also propagated in other samples but were reduced as the scanning speed was increased. Sample Z1 suffers more thermal stress due to large volume of deposit compared to other participating samples. These thermal stresses can have a significant effect on the strength and stability of the laser deposited samples. This however, can jeopardize the overall design of a structure. Some pores were also observed in the deposit as a result of the entrapped gas during cooling.

Figures 2 (a) to (c) show the circular wear track on the Ti6Al4V substrate and the laser deposited sample Z2. The inner and outer diameters of the wear track were measured using the optical microscope.

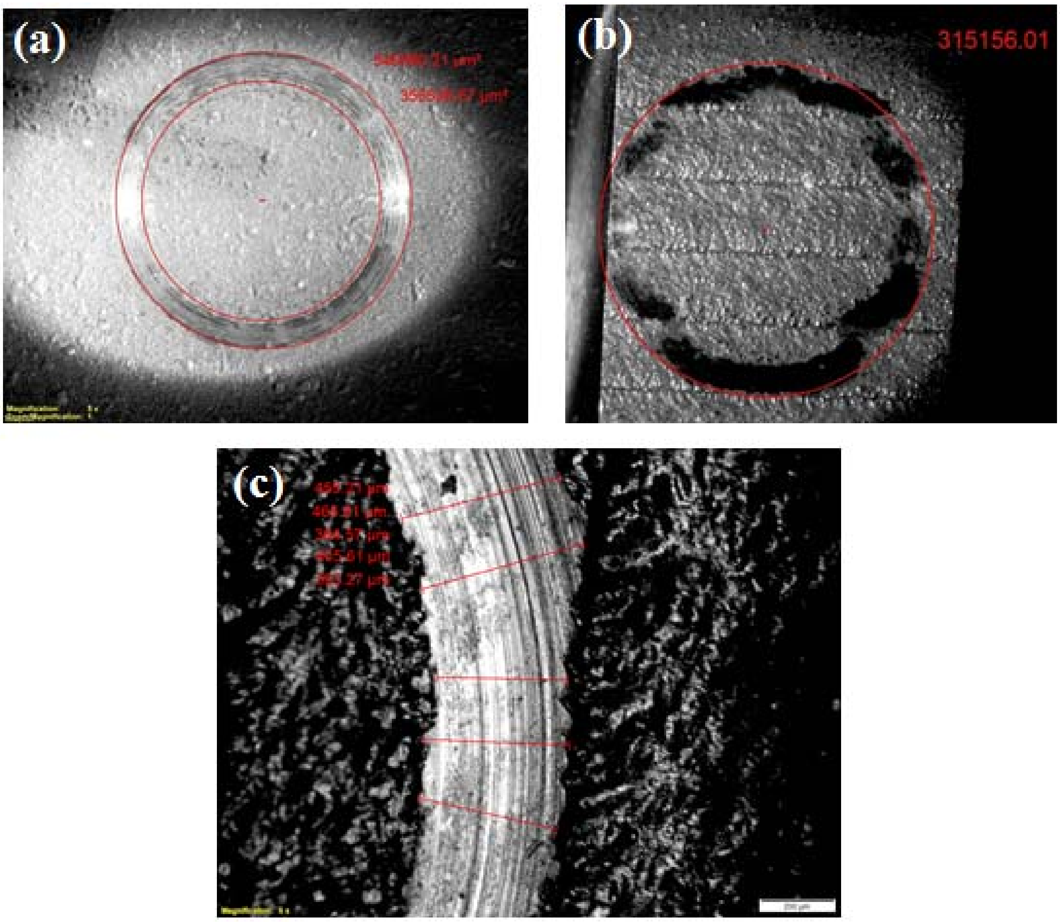

Figure 2: Wear track of the substrate and laser deposited sample Z2

The wear thickness of the samples was known by subtracting the inner diameter from the outer diameter. The wear thicknesses obtained for samples Z1, Z2, Z3 and Z4 are 0.35304 mm, 0.41691 mm, 0.19169 mm and 0.2476 mm respectively while that of the substrate is 0.46957 mm. Similarly, the depth of wear track for samples Z1, Z2, Z3 and Z4 are 0.062 mm, 0.051 mm, 0.056 mm and 0.0613 mm respectively while the substrate gave the lowest wear depth of 0.022 mm. The rolled and compressed nature of the substrate has enhanced the low depth result, and thus its relative smooth surface has also resulted in the highest thickness of 0.46957 mm compared to the laser deposited samples.

Figure 3 depicts the coefficient of friction (COF) of the laser deposited samples Z1, Z2, Z3, Z4 and the substrate.

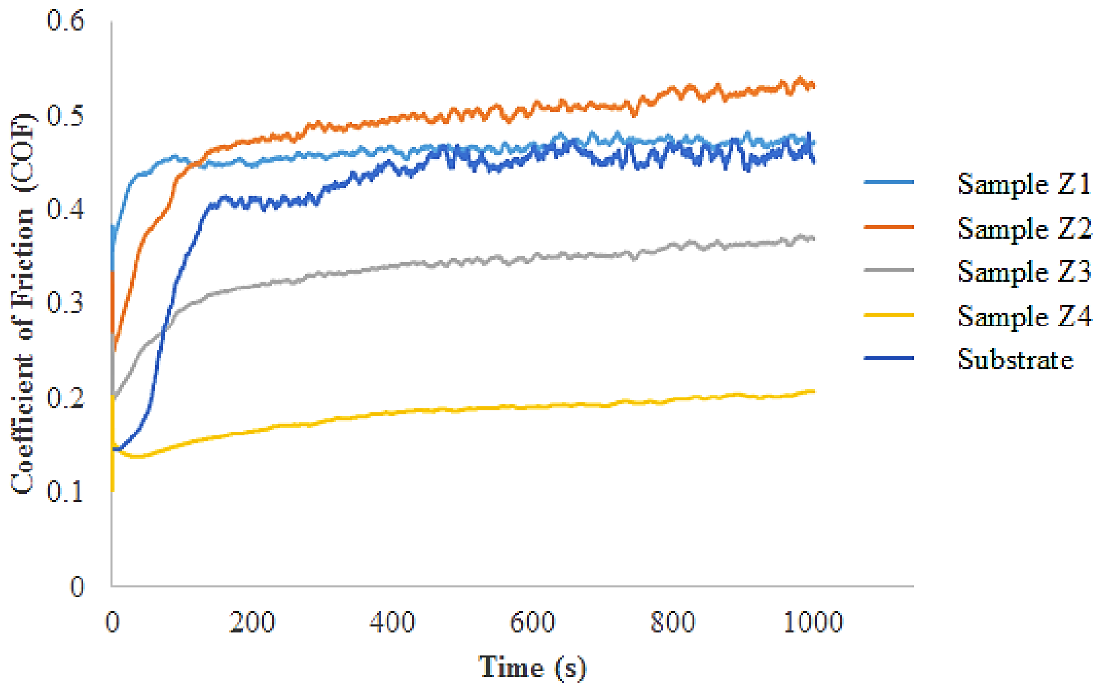

Figure 3: Coefficient of friction of the laser deposited samples Z1, Z2, Z3, Z4 and the substrate.

From the graph, sample Z1 shows a steady COF of 0.45 between 500 seconds and 1000 seconds. Sample Z2 displays the highest COF and maintains steady rise from approximately 0.47 to 0.54 and thus has a dominating positive gradient. Sample Z3 had a much lower COF between 0.2 and 0.36, and also maintains a gentle rise between 170 seconds and 1000 seconds. Sample Z4 had the least COF between 0.15 and 0.2 ans also show a gentle positive slope. The trend can be observed that the COF decreases with an increase in scanning speed. Only sample Z2 showed a rise in the COF over sample Z1 and this behaviour could be due to defect. The Substrate shows the rise in COF between 0.4 and 0.46 which is lower than the COF of samples Z1 and Z2.

3.0 Conclusion

The effect of the scanning speed on the wear properties of the laser deposited titanium alloy and copper has been analysed and reported. The melt pool created in the substrate decreases as the scanning speed was increased thereby decreasing the interaction time and the rate of cooling during solidification. The 50:50 weight percent of the blended powders has contributed to the lateral crack initiation due to the dissimilarities in the coefficient of thermal expansion of the two participating materials. Among the laser deposited samples, sample Z2 deposited at a laser power of 1.0 kW and scanning speed of 0.0167 mm exhibited the highest wear thickness of 0.41691 mm and lowest wear depth of 0.051 mm. The deposited samples can be used for repairing marine component in order to combat the problem of biofouling.

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